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DESCRIPTION

# CONTINUOUS CAST ALUMINUM ALLOY ROD AND PRODUCTION METHOD AND APPARATUS THEREOF

Cross Reference to Related Applications:

This application is an application filed under 35 U.S.C. §111(a) claiming the benefit pursuant to 35 U.S.C. §119(e)(1) of the filing date of Provisional Application No. 60/398,010 filed July 24, 2002 pursuant to 35 U.S.C. §111(b).

Technical Field:

The present invention relates to a continuously cast rod of aluminum alloy and to a method and apparatus for horizontally continuously producing the cast rod.

Background Art:

In general, horizontal continuous casting of molten metal produces an elongated cast ingot of cylindrical, square-columnar or hollow cylindrical form through the following process. Specifically, molten metal reserved in a tundish is teemed through a refractory passage into a tubular mold, which is substantially horizontally oriented and forcedly cooled, and then cooled in the mold to thereby form a solidification shell on the outer surface of the thus cooled molten metal. The resultant cast ingot is continuously removed from the mold, while a cooling agent (e.g., water) is sprayed directly onto the ingot to thereby

allow solidification of the interior of the ingot to proceed. However, such a horizontal continuous casting process inevitably involves the following problems because of its inherent principle.

A first problem will now be described. Since the mold is provided such that its center axis extends substantially horizontally, the molten metal in the mold is pressed, by means of gravitation, against the lower portion of the mold inner wall. Therefore, the molten metal is cooled in the mold in an unbalanced manner. That is, the lower portion of the molten metal is cooled more quickly than is the upper portion thereof. As a result, final solidification occurs above the center axis of the continuously cast rod, so the cast ingot fails to attain a uniform metallographic structure.

A second problem is as follows. When lubricant oil is fed, through a portion of the mold inner wall that is close to the inlet end of the mold, uniformly to the entirety of the mold inner wall in order to prevent seizure of the molten metal to the inner wall, the lubricant oil rises from the lower portion of the inner wall to the upper portion thereof because of the difference between gravity acting on the upper surface of the cast ingot and that acting on the lower surface thereof. In addition, a gas produced through thermal decomposition of the lubricant oil rises to the upper portion of the inner wall. Therefore, the lubrication interface that is present between the mold inner wall and the solidification shell formed on the periphery of the molten metal or the cast

ingot becomes non-homogenous. As described above, at the lower portion of the mold, since the molten metal is in contact with the mold inner wall, substantially no clearance is provided between the solidification shell and the mold inner wall. Thus, the lubricant oil fails to be fed to the solidification shell formed on the periphery of the molten metal or the cast ingot, leading to seizure between the molten metal and the mold inner wall. As a result, the solidification shell is broken, and outflow of unsolidified molten metal occurs, leading to generation of large casting defects or breakage of the cast ingot, whereby casting operation fails to be performed. Meanwhile, at the upper portion of the mold, since an excess amount of the lubricant oil is present, the molten metal is insufficiently cooled in the mold, and thus unsolidified molten metal flows out from the upper portion of the cast ingot.

Conventionally, various measures for solving such fundamental problems involved in the horizontal continuous metal casting process have been proposed. For example, JP-B HEI 8-32356 discloses a casting method in which pores or grooves are provided on the inner wall of a mold for preventing feeding of an excess amount of lubricant oil to the upper portion of the mold.

However, conventional casting processes (including the above proposed processes) encounter difficulty in preventing change in the surface conditions of a continuously cast rod since casting conditions (e.g., the feed volume of lubricant

oil, casting speed and casting temperature in a tundish), which have to be regulated very carefully, interact complicatedly with one another particularly when the cast rod undergoes actual production operation monitoring. As a result, seizure, breakouts and pits, which cause casting defects, tend to be generated.

In order to solve the aforementioned problems involved in the conventional horizontal continuous casting processes, objects of the present invention are to provide a continuously cast rod of aluminum alloy and a method and apparatus for horizontally continuously producing the cast rod, which prevents generation of casting surface defects and breakouts and which enables reliable continuous casting of a cast ingot of high quality.

Disclosure of the Invention:

The present invention provides a continuously cast aluminum alloy rod produced through a horizontal continuous casting process employing a tubular mold which is supported such that its center axis extends substantially horizontally and which has a forced cooling means, which rod comprises an Si-rich portion having a thickness of at least 20 μm on a surface of a lateral side of the rod that has a central angle of at least 30°.

In the continuously cast aluminum alloy rod, the Si-rich portion has a Si microstructure containing primary α-Al crystals whose percentage area is less than 50% as determined

in a micro-crystallographic image obtained from a radial cross section of the rod.

In the continuously cast aluminum alloy rod, the Si microstructure contains Si grains having an average grain size of 0.1 to 5 μm.

The continuously cast aluminum alloy rod contains Si in an amount of 7 to 14 mass%.

The continuously cast aluminum alloy rod contains Ca in an amount of at least 0.003 mass%.

The continuously cast aluminum alloy rod has a surface roughness Rmax of 50 μm or less and, when being subjected to peeling after casting, has no tool mark on the surface thereof.

The present invention also provides a method for producing a continuously cast aluminum alloy rod using a tubular mold which is supported such that its center axis extends substantially horizontally and which has a forced cooling means, which method comprises controlling a difference between a temperature of a molten aluminum alloy being teemed into the tubular mold and a solidification temperature thereof and casting a rod to form an Si-rich portion having a thickness of at least 20 μm on a surface of a lateral side of the rod having a central angle of at least 30°.

The method for producing a continuously cast aluminum alloy rod can further comprise controlling a removing speed of the rod from the tubular mold.

The method for producing a continuously cast aluminum alloy rod can further comprise employing as a raw material a molten aluminum alloy containing Si in an amount of 7 to 14 mass% and Ca in an amount of at least 0.003 mass%, regulating a casting speed to be 200 to 1,500 mm/min and the temperature of the molten aluminum alloy to be equal to or higher than a liquidus temperature of the alloy and using as the tubular mold a mold made of a material that is one species or a combination of two or more species selected from among aluminum, copper, and alloys thereof and having an effective mold length of 15 to 70 mm.

In the method for producing a continuously cast aluminum alloy rod, the molten aluminum alloy can be added with Ca in an amount of at least 0.003 mass%.

In the method for producing a continuously cast aluminum alloy rod, the Ca to be added is metallic Ca having a purity of at least 99.9 mass%.

In the method for producing a continuously cast aluminum alloy rod, the tubular mold includes, on its inner wall which comes into contact with the molten aluminum alloy, a ring-shaped permeable porous member having an air permeability of 0.005 to 0.03 L/($cm^2$ × min).

In the method for producing a continuously cast aluminum alloy rod, the permeable porous member is provided within a range of 5 to 15 mm of the effective mold length.

The present invention further provides an apparatus for producing a continuously cast aluminum alloy rod, comprising

a melting furnace which reserves therein molten aluminum alloy and from which the molten aluminum alloy is fed; a casting section which is provided with a cylindrical mold and a cooling means and at which the molten aluminum alloy is cast into a solidified cast ingot; a removal drive section at which the solidified cast ingot is removed substantially horizontally from the cylindrical mold to form a continuously cast aluminum alloy rod having a Si-rich portion; a detection section at which a region of the Si-rich portion is detected and from which detected signals are output; a determination section at which the detected signals are compared with preset determination conditions and from which determination signals are output; and a control unit that controls a temperature of the molten aluminum alloy in the melting furnace, the cooling means of the casting section and a removing speed of the removal drive section so that the detected signals fall within the preset determination conditions based on the determination signals.

The apparatus for producing a continuously cast aluminum alloy rod further comprises a Ca introducing section that is controlled by means of the control section so that the detected signals fall within the preset determination conditions based on the determination signals.

The apparatus for producing a continuously cast aluminum alloy rod further comprises an analysis section at which a composition of the molten aluminum alloy is analyzed and which outputs Ca amount measurement data signals based on

analyzed results to the determination section, and the control unit controls the Ca introducing section so that a Ca amount falls within the preset determination conditions based on the determination signals from the determination section.

According to the present invention, since a cast aluminum alloy rod is continuously formed under the aforementioned conditions using a tubular mold that is supported such that its center axis extends substantially horizontally and has a forced cooling means, it is possible to prevent generation of casting defects or breakouts of the cast ingot and to form on the upper surface of the cast aluminum alloy rod a strap-shaped Si-rich portion having a relatively high rigidity, compared with an ordinarily cast rod surface, that is suitable for suppressing occurrence of outflow of unsolidified molten metal caused by friction between the surface of the cast rod and the mold inner wall

Brief Description of the Drawings:

Fig. 1 is an explanatory view of the continuously cast rod of the present invention, Fig. 1(a) showing the appearance thereof and Fig. 1(b) showing the radial cross-section thereof.

Fig. 2 is a schematic cross-sectional view showing the principal part of an exemplary production apparatus employed in the production method of the present invention.

Fig. 3 is an explanatory view of the Si-rich portion of the continuously cast rod of the present invention, Fig. 3(a)

showing the process of collecting test pieces from the radial cross section of the continuously cast rod, Fig. 3(b) showing one example of the magnified micro-crystallographic image of the test piece and Fig. 3(c) showing another example of the magnified micro-crystallographic image of the test piece.

Fig. 4 is an explanatory view showing the effective mold length of the tubular mold in the production apparatus of Fig. 2.

Fig. 5 is a schematic view showing the configuration of an exemplary production apparatus according to the present invention.

Fig. 6 is a graph showing data obtained in Examples 1 to 4 of the present invention.

Fig. 7 is a graph showing data obtained in Examples 5 to 8 of the present invention.

Best Mode for Carrying out the Invention:

The continuously cast aluminum alloy rod of the present invention will now be described.

The continuously cast aluminum alloy rod of the present invention is produced through horizontal continuous casting process using a tubular mold that is supported such that its central axis extends substantially horizontally (i.e., in the lateral direction) and has a forced cooling means, and the cast rod has a diameter falling within a range of 10 to 100 mm. A cast rod having a diameter falling outside the above range may also be produced. However, the diameter preferably

falls within the above range since, when a cast rod having such a diameter is subjected to subsequent plastic working (e.g., forging, roll forging, drawing, rotation working or impact molding), small-sized and inexpensive equipment can be employed for such plastic working. When the diameter of a cast rod to be produced is changed, a detachable tubular mold having an inner diameter corresponding to the changed diameter of the cast rod is employed, and molten alloy temperature and casting speed are determined in accordance with the mold to be employed. If desired, the amounts of cooling water and lubricant oil are appropriately determined.

As shown in Fig. 1(a) and Fig. 1(b), the continuously cast aluminum alloy rod 101 of the present invention has a lengthwise (axially) strap-shaped Si-rich portion 104 having a thickness of at least 20 μm (preferably, 30 to 100 μm) on the surface of a lateral side (the peripheral surface) of the rod that has a central angle 103 of 30° or more (preferably, 40° to 90°) about the center 102 of the rod. The cast rod preferably has such a strap-shaped Si-rich portion in view of the fact that outflow of unsolidified molten alloy caused by friction between the surface of the cast rod and the mold inner wall can be prevented and that the cast rod does not raise any problem during the subsequent plastic working. When the central angle is less than 30° and the thickness is less than 20 μm, sufficient effects of the present invention fail to be obtained. In addition, while larger central angles are preferred, adjustment of the casting conditions

becomes stricter by the larger amount of central angle.

In the present invention, the thickness of the Si-rich portion is defined as follows. In order to obtain the thickness, firstly, the Si-rich portion is observed through the following procedure, for example.

(a) Sampling point, sampling method and preliminary treatment of samples:

Cast rod samples 101 are randomly collected from the continuously cast rod produced, and a test piece 306 that is 2 to 5 mm square is cut, as shown in Fig. 3(b), out of the lateral side surface of the sample 101 at a position corresponding to the upper portion of the mold inner wall. The test piece is sliced into thin pieces by use of a microtome, and each of the thin pieces is employed for observation of the radial cross section of the rod sample. Why the microtome is employed is as follows. Since the test piece to be observed is obtained from the very surface of the cast rod sample, when the test piece is sliced into thin pieces by means of a customary cutting technique, roll-off occurs in each of the pieces, so that reliable observation of the piece fails to be performed. So long as such a problem can be overcome, other cutting means may be employed.

In a manner similar to that described above, test pieces are cut out of several points of the lateral side in the circumferential direction of the cast rod sample.

(b) Measuring apparatus and measurement conditions:

An Al or Si micro-crystallographic image is obtained from the radial cross section by use of a field emission Auger electron spectroscopy (FE-AES) apparatus. The FE-AES apparatus may be, for example, MICROLAB-310F (product of VG). The radial cross section is observed under, for example, the following conditions: acceleration voltage: 10 kV, current applied to sample: 0.8 to 2.7 nA, magnification: × 1,000.

For surface observation, a secondary electron microscope or EPMA may be employed instead of the Auger electron microscope.

(c) Measurement of thickness and other data:

Fig. 3(b) schematically shows an image obtained through observation of the test sample 306 obtained from the continuously cast rod 101 of Fig. 3(a) by use of the Auger electron microscope. By use of the thus obtained image, the percentage area of α-Al 303 in an arbitrary region (10 μm square) extending from the surface of the cast rod toward the center thereof is obtained; a region in which the percentage area of α-Al is less than 50% is defined as a Si-rich portion 104; and the width of the Si-rich portion is defined as the thickness 302 thereof.

The percentage area of α-Al used herein refers to the ratio of the area of α-Al to that of the above specified region of the electron microscopic image, which is calculated by means of the point counting method.

The average size of Si grains 304 in the Si-rich portion, which is obtained through processing of the Auger electron microscopic image, is defined as the average grain size of Si grains contained in the Si microstructure.

In the continuously cast rod of the present invention, the Si-rich portion 104 preferably has a Si microstructure in which the percentage area of α-Al 303 is less than 50%, as shown in Fig. 3(c). When the percentage area of α-Al is less than 50%, the Si microstructural portion has hardness higher than that of a portion other than the microstructural portion, and casting reliability is further improved, which is preferable.

The average grain size of Si grains contained in the Si microstructure is preferably 0.1 to 5 μm. When the average grain size falls within the above range, the Si microstructure strengthens a solidification shell formed on the lateral side surface of the cast rod to thereby prevent outflow of unsolidified molten metal caused by friction between the surface of the cast rod and the mold inner wall. In addition, the cast rod does not raise any problem during the subsequent plastic working. The surface of the cast rod having the Si microstructure has a metallic gloss.

When the continuously cast rod of the present invention is produced through long-term casting operation, there can be prevented seizure between the cast rod and the inner wall of the mold, breakage of the cast rod or outflow of the molten alloy. As a result, the frequency of regulation of operation

conditions (e.g., the amount of lubricant oil to be fed and casting speed) can be reduced, whereby reliable casting operation can be performed.

The supposed mechanism by which the aforementioned effects are obtained is as follows. The continuously cast rod of the present invention has an Si-rich portion having a thickness of 20 μm or more on the surface of a lateral side of the rod that has a central angle of 30° or more, and thus the hardness of the surface of the cast rod is higher than that of the surface of a conventionally cast rod. Therefore, conceivably, the solidification shell becomes stronger in relation to the resistance of contact between the cast rod and the inner wall of the mold, and generation of casting defects (e.g., seizure) is suppressed. The portion of the cast rod having the Si microstructure has a metallic gloss and has hardness higher than that of another portion of the rod. Meanwhile, it is considered that the upper portion of the cast rod (i.e., the portion corresponding to the upper inner wall of the tubular mold which is oriented substantially horizontally) is insufficiently cooled since an excess amount of lubricant oil is present in that portion. When the Si-rich portion is formed in the upper portion of the cast rod, conceivably, the upper portion is reliably solidified, whereby outflow of unsolidified molten alloy can be prevented.

The continuously cast rod of the present invention preferably contains Ca in an amount of at least 0.003 mass%

(more preferably, 0.003 to 0.05 mass% and much more preferably, not less than 0.006, specifically, 0.006 to 0.04 mass%). This is because, when the cast rod contains Ca in such an amount, the hardness of the surface of the cast rod can be increased further. As a result, the aforementioned effects can be further enhanced.

The continuously cast rod of the present invention is employed as a material for subsequent plastic working, such as forging, roll forging, drawing, rotation working or impact molding. Alternatively, the cast rod is employed as a material for machining, such as bar machining or drilling, or similar processing. When the cast rod is subjected to plastic working or machining, before such a subsequent process, if desired, the Si microstructure is removed from the cast rod through peeling. Since the Si-rich portion and a cutting tool (e.g., a turning tool) employed for peeling exhibit no great difference in hardness, peeling of the continuously cast rod of the present invention can be readily performed. When peeling of the cast rod is performed, chips are fragmented at the Si-rich portion, and thus problems during peeling, such as entanglement of the cutting tool with chips, can be avoided. As a result, the cast rod of the present invention exhibits improved machinability, excellent finishing after peeling and good forgeability during the subsequent forging process, whereby, for example, the quality (e.g., dimensional accuracy) of the cast rod and the service life of a forging die are improved. When the surface of the

continuously cast rod is subjected to peeling, preferably, the resultant cast rod has a surface roughness Rmax of 50 μm or less, and has no tool mark. The term "tool mark" used herein refers to scratches formed by chips entering a cutting tool (e.g., a turning tool) employed for peeling, which are detected by means of visual inspection.

The entirety of the cast rod, including the peripheral upper portion having a high metallic gloss, has a very smooth casting surface. In addition, the cast rod contains no cavity in its interior and is suitable for use as a forging material.

Even when the continuously cast rod of the present invention is subjected to appropriate heat treatment without peeling, the cast rod exhibits mechanical characteristics required for subsequent working.

An exemplary apparatus employed in the present invention and the production method employing the apparatus will be described. The horizontal continuous casting method employed in the present invention may be a known horizontal continuous casting method. For example, there may be employed a horizontal continuous casting method in which one or more fluids selected from among a gas lubricant, a liquid lubricant and a gas obtained through thermal decomposition of the liquid lubricant are fed to the inner wall of a tubular mold which has a forced cooling means and which is supported such that its center axis extends substantially horizontally; a molten aluminum alloy containing Si is teemed into the

tubular mold through a first end thereof to thereby form a columnar molten alloy main body; the main body is solidified in the tubular mold to thereby form a cast ingot; and the cast ingot is removed from a second end of the tubular mold.

Fig. 2 shows an exemplary continuous casting apparatus, in the vicinity of a mold, employed in the present invention.

A tundish 250, a refractory plate-like body 210 and a tubular mold 201 are provided such that a molten alloy 255 reserved in the tundish 250 is teemed through the refractory plate-like body 210 into the tubular mold 201. The tubular mold 201 is supported such that a center axis 220 extends substantially horizontally. In order to solidify the molten alloy into a cast ingot 216, means for forcedly cooling the mold is provided in the interior of the tubular mold, and means for forcedly cooling the cast ingot is provided at the outlet of the tubular mold. As shown in Fig. 2, a cooling water-showering apparatus 205, which is an example of the means for forcedly cooling the cast ingot, is provided. In the vicinity of the outlet of the tubular mold, a driving apparatus (not illustrated) is provided so as to continuously remove the forcedly cooled cast ingot 216 from the mold at a predetermined rate. Furthermore, a synchronized cutting machine (not illustrated) is provided so as to cut the thus removed cast rod into pieces of predetermined length.

As shown in Fig. 2, the tubular mold 201 is supported such that the center axis 220 extends substantially horizontally. In addition, the tubular mold 201 includes the

means for forcedly cooling the mold, the means being provided for cooling the inner wall of the mold by feeding cooling water 202 into a mold's cooling water cavity 204 to thereby remove heat from a columnar molten alloy 215 filled in the mold via the mold inner wall with which the molten alloy is in contact, thereby forming a solidification shell on the surface of the molten alloy; and the forced cooling means provided for discharging cooling water from the showering apparatus 205 so as to apply the water directly to the cast ingot at the outlet of the mold, thereby solidifying the molten alloy in the mold. The tubular mold is connected, at the end opposite to the outlet of the showering apparatus, to the tundish 250 via the refractory plate-like body 210. As shown in Fig. 2, cooling water for forcedly cooling the mold and cooling water for forcedly cooling the cast ingot are supplied through a cooling-water feed tube 203. However, these two types of cooling water may be supplied separately. The forced cooling means and cooling water-showering apparatus of the tubular mold can preferably be controlled in their functions with control signals.

An effective mold length (reference letter L of Fig. 4) is defined as the length as measured from the point at which the center axis of the outlet of the cooling water-showering apparatus intersects the surface of the cast ingot to the contact surface between the mold and the refractory plate-like body. The effective mold length is preferably 15 to 70 mm. This is because, when the effective mold length falls

within the above range, a Si-rich portion having a thickness of 20 μm or more is sufficiently formed on the surface of a portion of the continuously cast rod that has a central angle of 30° or more. When the effective mold length is less than 15 mm, a good coating fails to be formed on the molten alloy, and thus casting of the molten alloy fails to be performed. In contrast, when the effective mold length exceeds 70 mm, the effect of forced cooling is not obtained, and thus the inner wall of the mold dominates solidification of the molten alloy, whereby the resistance of contact between the mold and the molten alloy or the solidification shell is increased, leading to unreliable casting (e.g., cracking occurring on the casting surface, or breakage of the cast ingot occurring in the mold).

The material of the mold is preferably one species or a combination of two or more species selected from among aluminum, copper and alloys thereof. The combination of these species may be determined from the viewpoint of thermal conductivity, heat resistance or mechanical strength.

The mold preferably includes, on its inner wall that comes into contact with the molten alloy, a ring-shaped permeable porous member 222 exhibiting self-lubricity. The ring-shaped member is provided over the entirety of the inner wall of the tubular mold. The air permeability of the permeable porous member is preferably 0.005 to 0.03 L/(cm$^2$ × min) (more preferably, 0.007 to 0.02 L/(cm$^2$ × min)). No particular limitations are imposed on the thickness of the

permeable porous member, but the thickness is preferably 2 to 10 mm (more preferably, 3 to 8 mm). This is because, when the thickness falls within the above range, a Si-rich portion having a thickness of 20 μm or more is sufficiently formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more. The permeable porous member may be formed of, for example, graphite having air permeability of 0.008 to 0.012 L/($cm^2$ × min). The air permeability is obtained by measuring the amount of air that permeates a test piece (thickness: 5 mm) per minute under application of a pressure of 2 kg/$cm^2$.

In the tubular mold, preferably, the permeable porous member is provided within a range of 5 to 15 mm of the effective mold length. This is because, when the permeable porous member is provided within the above range, a Si-rich portion having a thickness of 20 μm or more is sufficiently formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more. Preferably, an O-ring 213 is provided on the surface at which the refractory plate-like body, the tubular mold, and the permeable porous member are in contact with one another.

The radial cross section of the inner wall of the tubular mold may assume a circular shape, a triangular shape, a rectangular shape or an irregular shape having neither a symmetry axis nor a symmetry plane. When a hollow cast ingot is produced, a core may be provided in the interior of the tubular mold. The tubular mold has open ends. The molten

alloy is teemed through a first end of the mold (via an inlet provided in the refractory plate-like body) into the mold, and the solidified cast ingot is extruded or removed from a second end of the mold.

The inner diameter of the mold is increased toward the cast ingot removal direction such that the elevation angle between the mold inner wall and the center axis 220 is preferably 0 to 3° (more preferably, 0 to 1°). When the elevation angle is less than 0°, during removal of the cast ingot from the mold, resistance is applied to the cast ingot at the outlet of the mold, and thus casting fails to be performed. In contrast, when the elevation angle exceeds 3°, the molten alloy is incompletely brought into contact with the mold inner wall, and the mold insufficiently exerts the effect of removing heat from the molten alloy or the solidification shell, leading to insufficient solidification of the molten alloy. As a result, there is a high likelihood that casting problems occur. For example, a re-melted surface is formed on the cast ingot, or unsolidified molten alloy flows out from the end of the mold.

The tundish includes a molten alloy receiving opening 251, a molten alloy reservoir 252 and an outlet 253 through which the molten alloy is teemed into the mold. The tundish receives, through the inlet, a molten aluminum alloy whose composition is predetermined by means of, for example, a melting furnace provided outside of the casting apparatus. In the tundish, the level 254 of the molten alloy is

maintained at a position above the upper surface of the mold cavity. When multiple casting is performed, the molten alloy is reliably teemed from the tundish into a plurality of molds. The molten alloy reserved in the molten alloy reservoir of the tundish is teemed into the mold through a molten alloy inlet 211 provided in the refractory plate-like body. The melting furnace or tundish is preferably provided with a Ca introducing device, and it is preferable to control the amount of Ca to be introduced with control signals.

The refractory plate-like body 210 is provided for separating the tundish from the mold. The plate-like body may be formed of a refractory, adiathermic material. Examples of the material include Lumiboard (product of Nichias Corporation), Insural (product of Foseco Ltd.) and Fiber Blanket Board (product of Ibiden Co., Ltd.). The refractory plate-like body has a shape such that a molten alloy inlet can be formed therein. One or more molten alloy inlets may be formed in a portion of the refractory plate-like body that inwardly extends from the inner wall of the tubular mold.

Reference numeral 208 denotes a fluid feed tube for feeding a fluid. Examples of the fluid to be fed include lubrication fluids. The fluid may be one or more species selected from among a gaseous lubricant and a liquid lubricant. Preferably, a gaseous lubricant feed tube and a liquid lubricant feed pipe are separately provided. The fluid that is pressurized and fed through the fluid feed tube

208 passes through a circular path 224 and is fed to a clearance between the tubular mold and the refractory plate-like body. Preferably, a clearance of 200 μm or less is formed at a portion at which the mold and the refractory plate-like body are in contact with each other. The clearance has a size such that the molten alloy does not enter the clearance and that the fluid can flow therethrough to the mold inner wall. As shown in Fig. 2, the circular path 224 is provided on the periphery of the permeable porous member 222 provided in the tubular mold. The pressurized fluid permeates throughout the permeable porous member that comes into contact with the molten alloy, and is fed to the inner wall 221 of the tubular mold. In some cases, the liquid lubricant is decomposed into a gas through heating, and the gasified lubricant is fed to the inner wall of the tubular mold.

As a result, there can be improved lubricity between the permeable porous surface of the tubular mold and the periphery of the metallic mass that is the periphery of the columnar molten alloy main body or the periphery of the solidification shell. Since the ring-shaped permeable porous member is provided on the mold inner wall, an excellent lubrication effect is obtained, and there can be readily produced a continuously cast aluminum alloy rod having a Si-rich portion (thickness: 20 μm or more) formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more.

A corner space 230 is formed in the presence of one or more species selected from among the fed gaseous and liquid lubricants, and the gas obtained through decomposition of the liquid lubricant.

The production method of the present invention will now be described.

As shown in Fig. 2, the molten alloy in the tundish 250 is teemed through the refractory plate-like body 210 into the tubular mold 201 that is supported such that its center axis extends substantially horizontally, and the molten alloy is forcedly cooled and solidified at the outlet of the mold to thereby form the cast ingot 216. The cast ingot 216 is continuously removed from the mold at a predetermined rate by use of the driving apparatus provided in the vicinity of the outlet of the mold to thereby form a cast rod. The resultant cast rod is cut into pieces of predetermined length by use of the synchronized cutting machine.

When the continuously cast aluminum alloy rod is produced, the composition and temperature of the molten alloy are determined such that a Si-rich portion having a thickness of 20 μm or more is formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more. Thus, it is considered that the state of a solidification interface 217 of the molten alloy and the state of the corner space 230 are stabilized. As a result, reliable casting operation can be performed. The effective mold length is also determined such that a Si-rich portion

having a thickness of 20 μm or more is formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more.

The composition of the molten aluminum alloy 255 that is reserved in the tundish will now be described. The molten aluminum alloy preferably contains Si in an amount of 7 to 14 mass% (more preferably, 8 to 13 mass% and much more preferably, 12 to 13 mass%) and metallic Ca in an amount of at least 0.003 mass% (more preferably, 0.003 to 0.04 mass% and much more preferably, 0.003 to 0.03 mass%). In addition to these components, the molten alloy preferably contains iron (0.1 to 0.5 mass%), copper (2.0 to 9.0 mass%), Mn (0 to 0.5 mass%) and Mg (0.2 to 1.0 mass%).

The molten aluminum alloy containing Si in an amount of 8 to 13 mass% is particularly preferred since the resultant cast ingot exhibits excellent mechanical characteristics because of formation of a lamellar microstructure by aluminum and silicon contained in the cast ingot, and the cast ingot exhibits enhanced wear resistance attributed to the presence of hard silicon.

The relation between the Ca content of the alloy and the amount of Ca added thereto will now be described.

When Ca is inevitably contained in the alloy, the Ca content of the alloy as determined through analysis is the total amount of (1) Ca that is inevitably contained in raw materials of the alloy (the Ca is derived mainly from Ca-mingled metallic silicon serving as a raw material) and (2)

Ca that is added to the molten alloy. For example, when Ca is not added to the molten alloy, Ca detected in the resultant cast ingot is derived from the raw material and is inevitably contained in the cast ingot. Meanwhile, when Ca is added to the molten alloy, the amount of the added Ca is obtained by subtracting the amount of the inevitable Ca from the total amount of Ca contained in the cast ingot.

In the present invention, the amount of Ca contained in the alloy is preferably 0.003 mass% or more. Particularly, the amount of Ca added to the alloy is preferably 0.003 mass% or more. The total amount of the added Ca and the inevitable Ca in the cast ingot is preferably 0.004 mass% or more (more preferably, 0.004 to 0.05 mass% and much more preferably 0.05 mass% or less). This is because, when the total amount of Ca falls within the above range, formation of a Si-rich portion is promoted, and silicon grains in the cast ingot are micronized, whereby mechanical characteristics of the cast ingot are improved.

The inevitable Ca is contained in metallic silicon serving as a raw material of the molten aluminum alloy, and thus is considered to be present in the form of calcium silicate. Meanwhile, conceivably, the Ca added to the molten aluminum alloy does not form an oxide in the alloy. Therefore, in order to promote formation of a Si-rich portion and to micronize silicon grains in the cast ingot, preferably, the amount of the Ca to be added is regulated to at least 0.003 mass%, more preferably, 0.003 to 0.03 mass%.

The Ca added to the alloy is preferably metallic Ca having a purity of at least 99.9 mass%. The Ca is preferably in the form of granules from the viewpoint of ease of operation. After adjustment of elemental components, other than Ca, of the molten alloy is completed, Ca granules are added to the molten alloy. In order to prevent oxidation of the Ca granules during the course of addition, preferably, the granules are coated with aluminum foil before addition thereof.

The compositional proportions of alloy components of the cast ingot can be confirmed by means of, for example, the method specified by JIS H 1305 employing an optical emission spectrometer (e.g., PDA-5500, product of Shimadzu Corporation), which is based on photoelectric photometry.

The difference in height between the level 254 of the molten alloy reserved in the tundish and the top surface of the mold inner wall is preferably 0 to 250 mm (more preferably, 50 to 170 mm). This is because, when the difference in height falls within the above range, the pressure of the molten alloy teemed into the mold is well balanced with the pressures of a liquid lubricant and a gas obtained through gasification of the lubricant, and thus castability is improved, and there can be readily produced a continuously cast aluminum alloy rod having a Si-rich portion (thickness: 20 μm or more) formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more. When a level sensor is provided on the tundish

for measuring and monitoring the level of the molten alloy, the level of the alloy can be accurately controlled to thereby maintain the aforementioned difference in height at a predetermined value.

The liquid lubricant may be a vegetable oil that functions as lubricant oil. Examples of the vegetable oil include rapeseed oil, castor oil and salad oil. Employment of such vegetable oil is preferred since it less adversely affects the environment.

The feed amount of the lubricant oil is preferably 0.05 to 5 mL/minute (more preferably, 0.1 to 1 mL/minute). This is because, when the feed amount falls within the above range, a Si-rich portion having a thickness of 20 μm or more is sufficiently formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more. When the feed amount is excessively small, breakouts of the cast ingot are generated due to poor lubricity, whereas when the feed amount is excessively large, excess lubricant oil enters the cast ingot, causing internal defects of the ingot.

The rate at which the cast ingot is removed from the mold (i.e., casting speed) is preferably 200 to 1,500 mm/minute (more preferably, 400 to 1,000 mm/minute). This is because, when the casting speed falls within the above range, a Si-rich portion having a thickness of 20 μm or more is sufficiently formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more, and as a result, castability is not impaired even when

production conditions vary, as well as the cast ingot having a fine, uniform structure can be obtained at high cooling rate.

The volume of cooling water, per mold, supplied from the cooling water-showering apparatus to the mold is preferably 5 to 30 L/minute (more preferably, 25 to 30 L/minute). When the amount of cooling water is excessively small, a Si-rich portion having a thickness of 20 μm or more is insufficiently formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more. As a result, breakouts may be generated, and the surface of the cast ingot may be re-melted to thereby form a non-uniform structure, which may remain in the cast ingot as an internal defect. In contrast, when the amount of cooling water is excessively large, a very large amount of heat is removed from the mold, whereby casting fails to be performed.

The average temperature of the molten alloy teemed from the tundish into the mold is preferably 600 to 750°C (more preferably, 640 to 680°C), since a Si-rich portion having a thickness of 20 μm or more is sufficiently formed on the surface of a lateral side of the continuously cast rod that has a central angle of 30° or more. When the temperature of the molten alloy is excessively low, large crystallization products are formed in the mold or at a position upstream the mold, and the products are taken into the cast ingot in the form of internal defects. In contrast, when the temperature of the molten alloy is excessively high, a large amount of

hydrogen gas is taken into the molten alloy, and porosity (i.e., internal defect) occurs in the cast ingot.

The method for detecting and determining the strap-shaped Si-rich portion formed lengthwise on the surface of a continuously cast rod according to the present invention will be described herein below with reference to Fig. 5.

Fig. 5 is a schematic view showing the configuration of one example of an apparatus 501 for producing a continuously cast rod of aluminum alloy according to the present invention.

The producing apparatus 501 comprises a melting furnace 502 in which molten aluminum alloy is produced, a Ca introducing device 503 that introduces Ca into the melting furnace 502, a casting apparatus 504 which has the configuration shown in Fig. 2 and into which molten aluminum alloy fed from the melting furnace 502 is fed, a removal drive device 505 that removes from the casting apparatus 504 a continuously cast rod 101 of aluminum alloy cast with the casting apparatus 504, a detection section 506 that detects a region of a Si-rich portion formed on the surface of the continuously cast rod 101 and outputs detection signals, an analysis section 507 that analyzes the continuously cast rod 101 in its composition and outputs Ca content measurement data signals, a determination section 508 that compares the output signals from the detection section 506 and analysis section 507 with preset determination conditions and outputs determination signals based on the comparison, and a control unit 509 that controls each section based on the output

signals so that the determination signals fall within the preset determination conditions. It is noted that the analysis section can be omitted, and the control unit can comprise a plurality of control units disposed in a scattered manner.

The melting furnace 502 is provided with a heater (not shown) and a temperature detector (not shown). The heater is controlled by means of the control unit 509 to maintain the furnace interior temperature at a predetermined temperature, and the temperature detector detects the furnace interior temperature and outputs a detected temperature to the control unit 509. There are also provided devices (not shown), other than the Ca introducing device, for introducing into the melting furnace 502 metal components for the formation of molten aluminum alloy. Each of the introducing devices including the Ca introducing device 503 is equipped with an introducing mechanism (not shown) and a detector (not shown) for detecting the amount introduced. Each introducing mechanism is controlled by means of the control unit 509 to introduce each metal into the melting furnace 502, and each detector detects the amount introduced and outputs the detected amount to the control unit 509. The casting apparatus 504 is equipped with a lubrication means (not shown), and cooling means (not shown) and temperature detectors (not shown) for the metal components. The lubrication means and cooling means are controlled by means of the control unit 509 to cool the molten aluminum alloy

into a continuously cast rod 101 of aluminum alloy, and the temperature detectors detect the tundish interior temperature and mold interior temperature and outputs the detected temperatures to the control unit 509. The removal drive 505 is equipped with a speed detector (not shown) for detecting the removing speed and controlled by means of the control unit 509 to remove the continuously cast rod of aluminum alloy from the casting apparatus 504, and the speed detector detects the removing speed and outputs the detected speed to the control unit 509.

In view of the fact that a Si-rich portion of the continuously cast rod 101 of aluminum alloy differs in surface property from other portion thereof, the detection section 506 can adopt any detector insofar as the difference can be detected. Since the surface of the Si-rich portion has a metallic gloss and/or a different degree of roughness, a detector that detects reflectance and/or surface roughness, for example, can be adopted in order to detect the metallic gloss and/or degree of roughness. An optical, supersonic or capacitance detector is particularly advantageous because it can perform detection in a non-contact state. Since the detector is required to detect the region of the Si-rich portion, it has to have a function of covering the overall surface of the continuously cast rod of aluminum having the above surface property to be detected or a function of scanning the detection range.

From the detection section 506 detection signals corresponding to results of the position and surface property of the Si-rich portion of the continuously cast rod 101 of aluminum alloy detected are output to the determination section 508.

The determination section 508 has the preset determination conditions therein and compares the detected signals on the Si-rich portion from the detection section 506 and the analysis results, i.e. the Ca amount measurement data signals, from the analysis section 507 with the preset determination conditions. For example, it detects a portion at which the difference arises among the surface property results as a boundary between the Si-rich portion and the other portion to determine the region of the Si-rich portion. It further has a function to feed back to the control unit 509, control signals that control casting conditions based on the results of the aforementioned comparison and determination.

The signal processing, determination processing and condition-setting processing can be performed using either analogue or digital signals.

The conditions for determining the Si-rich portion include reflectance and surface roughness of the region corresponding to the lateral side surface of the continuously cast rod 101 of aluminum alloy having a central angle of at least 30°.

Molten aluminum alloy temperature and casting speed are controlled in casting. Therefore, by elevating the molten aluminum alloy temperature, for example, based on the signals of the continuously cast rod 101 of aluminum alloy produced in the casting apparatus 504, which signals are detected at the detection section 506, the portion having a metallic gloss can be widened. The reason for this is that the difference between the aluminum alloy melting temperature and the solidification temperature gives rise to a difference in the state of solidification, conceivably resulting in controllability in formation of a metallic gloss. The same is conceivably applicable to the casting speed. The molten aluminum alloy temperature can be adjusted by control of the heating temperature for the melting furnace 502, heating to the metal components fed midway to and inside the tundish for thermal insulation, etc. The casting speed can be adjusted using an apparatus capable of adjusting the forced cooling of the mold, amount of cooling water from the cooling water-showering apparatus, removing speed of the removal drive device 505 and molten aluminum alloy temperature.

It is preferred to further include the amount of Ca to be added as what is to be controlled in casting because this increases the degree of freedom of setting the casting conditions. As shown in Fig. 5, the Ca introducing device 503 is disposed as Ca adding means in parallel to the introducing devices (not shown) for introducing into the melting furnace 502 metal components for the formation of

molten aluminum alloy. By so doing, the amounts of the metal components and Ca to be introduced can be readily controlled in combination. The function of the addition of Ca decreases the solidification temperature and varies the difference between the melting temperature and the solidification temperature, giving rise to a difference in the state of solidification. This conceivably enables formation of a metallic gloss to be controlled. The same effect can be obtained if Ca is introduced directly into the tundish.

In order to manage the amount of Ca to be added with higher precision, it is preferred to provide the analysis section 507 for transmitting to the determination section 508 data of the Ca amount measurement results obtained through analysis of the composition of the cast product and to control the molten aluminum alloy temperature, casting speed and Ca amount to be added based on the added Ca amount data and determination results of the region of the Si-rich portion. This is because it is possible to control the amount of Ca to be added to not less than 0.003 mass% with exactitude and also control the region of the Si-rich portion.

No particular restriction is imposed on the composition-analyzing method insofar as it can detect the Ca amount. Either a method that can initiate analysis of the Ca amount from the surface of the rod immediately after casting or a method that can measure the Ca amount off-line after removal of a sample. A method using a measuring time of not more than 1 hour is preferable. For example, an emission

spectroscopic analysis can be cited for the Ca amount measurement.

With this apparatus, it is possible to produce, with ease, a continuously cast aluminum alloy rod having a Si-rich portion having a thickness of at least 20 μm on a surface of a lateral side of the rod that has a central angle of at least 30°.

Since the Si-rich portion formed on the upper surface of the continuously cast aluminum alloy rod suppresses seizure and breakouts, it is possible to stably produce a continuously cast aluminum alloy rod.

The method for producing a continuously cast aluminum alloy rod using this production apparatus controls the difference between the molten aluminum alloy temperature and its solidification temperature or both that difference and the speed at which the continuously cast aluminum alloy rod is to be removed from the tubular mold, thereby easy production of a continuously cast aluminum alloy rod having a Si-rich portion having a thickness of at least 20 μm on a surface of a lateral side of the rod that has a central angle of at least 30°.

Since the Si-rich portion formed on the upper surface of the continuously cast aluminum alloy rod suppresses seizure and breakouts, it is possible to stably produce a continuously cast aluminum alloy rod.

Examples of the present invention will be described below, but the invention is not limited to these Examples.

Examples 1 through 4:

Metallic Ca was added to an aluminum alloy containing Si in an amount of 12 mass% (Ca content: 0.003 mass% in Example 1, 0.006 mass% in Example 2, 0.01 mass% in Example 3 and 0.03 mass% in Example 4). The resultant molten alloy was subjected to horizontal continuous casting by use of the apparatus shown in Fig. 2 to thereby form a billet (diameter: 30 mm). A permeable porous member formed of graphite having air permeability of 0.01 L/($cm^2$ × min) was employed in the mold. The casting conditions were as follows.

(1) Difference in height between the level of the molten alloy in the tundish and the upper portion of the mold inner wall: 150 mm

(2) Lubricant oil: rapeseed oil

(3) Feed amount of the lubricant oil: 0.2 mL/minute

(4) Casting speed: 900 mm/minute

(5) Feed amount of cooling water: 25 L/minute

(6) Average temperature of the molten alloy in the tundish: 660°C

Comparative Example 1:

The procedure of Example 1 was repeated except that metallic Ca was not added to the aluminum alloy to thereby perform horizontal continuous casting.

Fig. 6 is a graph showing the relation between the casting time on the horizontal axis and the frequency of occurrence of casting problems (the number of problems

occurring within 30 minutes) on the vertical axis in the respective Examples and Comparative Example 1. The term "casting problem" refers to stopping of casting operation caused by generation of breakouts or breakage of the billet. The mold was exchanged immediately after stopping of casting operation, and then casting operation was resumed.

In each of Examples 1 through 4 (total number of actual casting operations: 100), casting conditions were stabilized, and the frequency of occurrence of casting problems (e.g., outflow of the molten alloy or breakage of the billet) was reduced. The thus produced cast rod was found to have, on the upper portion of the periphery thereof, a very smooth casting surface containing a portion having a high metallic gloss, and to have no cavity in the interior of the cast rod.

The structure of the metallic gloss portion was observed, and the portion was found to have a Si microstructure containing $\alpha$-Al whose percentage area is less than 50%.

In Comparative Example 1 (total number of actual casting operations: 100), casting conditions were not stabilized, and change in casting surface conditions occurred. Seizure between the cast rod and the mold inner wall, breakage of the cast rod or outflow of the molten alloy from the mold caused by such breakage occurred. When such problem occurred, the casting operation was stopped, and either the feed amount of the lubricant oil or the casting speed was required to be regulated, leading to poor production

efficiency. The surface of the thus produced cast rod was visually observed. As a result, the upper casting surface of the rcd was found to have a cyclical scaly pattern, and the lower casting surface thereof was found to have large and small seizure portions. Such abnormal surface conditions adversely affected the deep interior of the cast rod.

Tables 1 through 3 show the results of the respective Examples and Comparative Example 1, specifically, the results of analysis of the composition of the alloy in Table 1, and the results of measurement of physical properties of the Si-rich portion in Tables 2 and 3.

Table 1

[Mass%]

| | Amount of added Ca (mass%) | Si | Fe | Cu | Mn | Mg | Cr | Ni | Zn | Ti | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Example 1 | 0.003 | 11.50 | 0.27 | 4.26 | 0.26 | 0.56 | 0.009 | 0.013 | 0.005 | 0.005 | 0.0050 |
| Example 2 | 0.006 | 11.49 | 0.28 | 4.23 | 0.25 | 0.57 | 0.008 | 0.012 | 0.008 | 0.006 | 0.0076 |
| Example 3 | 0.01 | 11.39 | 0.28 | 4.21 | 0.26 | 0.58 | 0.008 | 0.013 | 0.005 | 0.006 | 0.0118 |
| Example 4 | 0.03 | 11.39 | 0.28 | 4.29 | 0.25 | 0.57 | 0.008 | 0.014 | 0.005 | 0.007 | 0.0355 |
| Example 5 | 0.003 | 11.44 | 0.25 | 4.15 | 0.25 | 0.55 | 0.008 | 0.013 | 0.007 | 0.007 | 0.0047 |
| Example 6 | 0.006 | 11.28 | 0.27 | 4.22 | 0.26 | 0.55 | 0.009 | 0.014 | 0.006 | 0.008 | 0.0081 |
| Example 7 | 0.01 | 11.18 | 0.24 | 4.19 | 0.26 | 0.57 | 0.008 | 0.012 | 0.008 | 0.007 | 0.0093 |
| Example 8 | 0.03 | 11.23 | 0.27 | 4.08 | 0.25 | 0.56 | 0.007 | 0.015 | 0.007 | 0.005 | 0.0347 |
| Comparative Example 1 | 0 | 11.45 | 0.24 | 4.18 | 0.25 | 0.57 | 0.008 | 0.012 | 0.004 | 0.005 | 0.0019 |
| Comparative Example 2 | 0 | 11.48 | 0.25 | 4.2 | 0.25 | 0.58 | 0.008 | 0.011 | 0.005 | 0.005 | 0.0017 |

Table 2

| | Thickness of Si-rich portion (μm) | Amount of added Ca (mass%) |
|---|---|---|
| Example 1 | 18 | 0.003 |
| Example 2 | 25 | 0.006 |
| Example 3 | 23 | 0.01 |
| Example 4 | 32 | 0.03 |
| Example 5 | 20 | 0.003 |
| Example 6 | 23 | 0.006 |
| Example 7 | 28 | 0.01 |
| Example 8 | 35 | 0.03 |
| Comparative Example 1 | 10 | 0 |
| Comparative Example 2 | 0 | 0 |

Table 3

| | Angle of glossy portion (°) | Amount of added Ca (mass%) |
|---|---|---|
| Example 1 | 50 | 0.003 |
| Example 2 | 59 | 0.006 |
| Example 3 | 55 | 0.01 |
| Example 4 | 72 | 0.03 |
| Example 5 | 38 | 0.003 |
| Example 6 | 46 | 0.006 |
| Example 7 | 55 | 0.01 |
| Example 8 | 63 | 0.03 |
| Comparative Example 1 | 19 | 0 |
| Comparative Example 2 | 0 | 0 |

Examples 5 through 8:

Metallic Ca was added to an aluminum alloy containing Si in an amount of 12 mass%, Cu in an amount of 4 mass% and Mg in an amount of 0.5 mass% (Ca content: 0.003 mass% in Example 5, 0.006 mass% in Example 6, 0.01 mass% in Example 7 and 0.03 mass% in Example 8). The resultant molten alloy was subjected to horizontal continuous casting by use of the

apparatus shown in Fig. 2 to thereby form a billet (diameter: 50 mm). A permeable porous member formed of graphite having air permeability of 0.01 L/($cm^2$ × min) was employed in the mold. The casting conditions were as follows.

(1) Difference in height between the level of the molten alloy in the tundish and the upper portion of the mold inner wall: 170 mm

(2) Lubricant oil: rapeseed oil

(3) Feed amount of the lubricant oil: 0.3 mL/minute

(4) Casting speed: 900 mm/minute

(5) Feed amount of cooling water: 30 L/minute

(6) Average temperature of the molten alloy in the tundish: 660°C

Comparative Example 2:

The procedure of Example 5 was repeated except that metallic Ca was not added to the aluminum alloy to thereby perform horizontal continuous casting.

Fig. 7 is a graph showing the relation between the casting time on the horizontal axis and the frequency of occurrence of casting problems on the vertical axis in the respective Examples and Comparative Example 2. As in the case of Example 1, the results of continuous casting performed in each of the Examples were excellent. That is, casting defects were drastically reduced. In each of the Examples (total number of casting operations: 100), casting conditions were very stabilized, and the frequency of

occurrence of operation problems (e.g., outflow of the molten alloy or breakage of the billet) was reduced.

A portion having a high metallic gloss formed on the upper surface of the cast rod was subjected to measurement in terms of hardness. The surface of the cast rod of each of Examples 5 through 8, in which metallic Ca was added to the alloy, was found to have relatively high hardness as compared with that of the cast rod of Comparative Example 2, in which no metallic Ca was added to the alloy. The metallic gloss portion, which is formed on the upper surface of only the cast rod containing metallic Ca, has hardness relatively higher than that of another portion of the cast rod. Conceivably, when the metallic gloss portion is formed on the upper portion of the cast rod, there can be prevented outflow of unsolidified molten alloy from the upper portion of the cast rod, which corresponds to the upper portion of the mold inner wall at which the molten alloy is insufficiently cooled due to the presence of an excess amount of lubricant oil.

The structure of the metallic gloss portion was observed, and the portion was found to have a Si microstructure containing α-Al whose percentage area is less than 50%.

In contrast to the case of the above Examples, in Comparative Example 2 (total number of casting operations: 100), casting conditions were not stabilized, and change in casting surface conditions occurred. Seizure between the cast rod and the mold inner wall, breakage of the cast rod or

outflow of the molten alloy from the mold caused by such breakage occurred. When such problem occurred, the casting operation was stopped, and either the feed amount of the lubricant oil or the casting speed was required to be regulated, leading to poor production efficiency. The upper surface of the cast rod of Comparative Example 2, in which no metallic Ca was added to the molten alloy, was found to have a cyclical scaly pattern. In addition, the upper surface of the cast rod was found to have no Si-rich portion, and the structure of the upper surface was found to be the same as that of the interior of the cast rod.

Tables 1 through 3 show the results of the respective Examples and Comparative Example 2, specifically, the results of analysis of the composition of the alloy, and the results of measurement of physical properties of the Si-rich portion.

Table 4 shows the results of measurement of the average grain size of Si grains contained in the Si microstructure of the cast rod of each Example.

Table 4

| | Si average grain size (μm) | Amount of added Ca (mass%) |
|---|---|---|
| Example 1 | 1.0 | 0.003 |
| Example 2 | 1.1 | 0.006 |
| Example 3 | 0.9 | 0.01 |
| Example 4 | 1.1 | 0.03 |
| Example 5 | 0.9 | 0.003 |
| Example 6 | 0.8 | 0.006 |
| Example 7 | 1.1 | 0.01 |
| Example 8 | 1.2 | 0.03 |

Examples 9, 10, 11 and 12:

The procedure of Example 5 was repeated except that a permeable porous member having the following air permeability was employed: 0.008 L/(cm$^2$ × min) in Example 9, 0.012 L/(cm$^2$ × min) in Example 10, 0.001 L/(cm$^2$ × min) in Example 11 or 0.1 L/(cm$^2$ × min) in Example 12 to thereby perform horizontal continuous casting.

In Examples 9 and 10, results comparable to those of Example 5 were obtained. In Example 11, the frequency of occurrence of casting problems (i.e., stopping of casting operation) did not increase drastically, but the lubrication effect was insufficiently obtained, and the following problems tended to occur: seizure on the surface of the cast rod, breakage of the cast rod and unreliable casting operation. In Example 12, the frequency of occurrence of casting problems (i.e., stopping of casting operation) did not increase drastically, but an excess amount of the lubricant oil was present in the mold, and the following problems tended to occur: outflow of the molten alloy due to insufficient cooling, invasion of intermediates into the surface or interior of the cast rod and unreliable casting operation.

Industrial Applicability:

As described above, the present invention provides a method for producing a continuously cast aluminum alloy rod such that the cast rod has a Si-rich portion having a

thickness of 20 μm or more on the surface of a lateral side of the rod that has a central angle of 30° or more. Therefore, according to the present invention, reliable casting operation can be realized.